NASA TM X-195

NASA TM X-195

N63 380002

TECHNICAL MEMORANDUM

X-195

LAUNCH, LOW-SPEED, AND LANDING

CHARACTERISTICS DETERMINED FROM THE FIRST FLIGHT OF THE

NORTH AMERICAN X-15 RESEARCH AIRPLANE

By Thomas W. Finch and Gene J. Matranga

High-Speed Flight Station
Edwards, Calif.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON

September 1959
Declassified April 12, 1961

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL MEMORANDUM X-195

LAUNCH, LOW-SPEED, AND LANDING CHARACTERISTICS DETERMINED FROM THE FIRST FLIGHT OF THE NORTH AMERICAN X-15 RESEARCH AIRPLANE*

By Thomas W. Finch and Gene J. Matranga

SUMMARY

The first flight of the North American X-15 research airplane was made on June 8, 1959. This was accomplished after completion of a series of captive flights with the X-15 attached to the B-52 carrier airplane to demonstrate the aerodynamic and systems compatibility of the X-15/B-52 combination and the X-15 subsystem operation. This flight was planned as a glide flight so that the pilot need not be concerned with the propulsion system. Discussions of the launch, low-speed maneuvering, and landing characteristics are presented, and the results are compared with predictions from preflight studies.

The launch characteristics were generally satisfactory, and the X-15 vertical tail adequately cleared the B-52 wing cutout.

The actual landing pattern and landing characteristics compared favorably with predictions, and the recommended landing technique of lowering the flaps and landing gear at a low altitude appears to be a satisfactory method of landing the X-15 airplane. There was a quantitative correlation between flight-measured and predicted lift-drag-ratio characteristics in the clean configuration and a qualitative correlation in the landing configuration.

A longitudinal-controllability problem, which became severe in the landing configuration, was evident throughout the flight and, apparently, was aggravated by the sensitivity of the side-located control stick.

In the low-to-moderate angle-of-attack range covered, the longitudinal and directional stability were indicated to be adequate.

---

*Title, Unclassified.

For the small deflections used, the characteristics of the rolling tail appeared satisfactory.

Near a Mach number of 0.6, buffet onset occurred at a normal-force coefficient of about 0.6.

INTRODUCTION

This paper presents results from the first flight of the North American X-15 research airplane which was conducted at Edwards Air Force Base, Calif., by the manufacturer. The first flight was unpowered to enable the pilot to concentrate on the launch and landing characteristics and on systems operation. Some flight measurements and analysis of the launch characteristics, low-speed maneuvering characteristics pertinent to the landing, and landing characteristics are presented.

Since the estimated lift-drag ratio of the X-15 was lower than that attained on previous rocket airplanes, a considerable effort was expended by North American Aviation, the U. S. Air Force, and the NASA High-Speed Flight Station prior to flight to determine the techniques required for the approach and landing maneuvers. From an analog study and flight tests of a simulated X-15 configuration, conducted by the NASA, it was recommended that a technique be used in which gear and flap extensions are delayed to a minimum altitude of less than 500 feet. The results of these investigations are presented in reference 1 and unpublished data.

Primary areas of emphasis in the glide-flight results reported herein are the comparisons of actual launch and landing characteristics with predicted characteristics.

SYMBOLS

a_n	normal acceleration, g units
C_L	airplane lift coefficient
g	acceleration due to gravity, ft/sec^2
h	geometric altitude, ft
L/D	lift-drag ratio
M	Mach number

p	rolling velocity, deg/sec
q	pitching velocity, deg/sec
r	yawing velocity, deg/sec
t	time, sec
V_i	indicated airspeed, knots
V_v	vertical velocity, ft/sec
Z	separation distance between X-15 and B-52, ft
α	angle of attack, deg
β	angle of sideslip, deg
δ_a	total aileron deflection (left horizontal-tail deflection minus right horizontal-tail deflection), deg
δ_f	flap deflection, deg
δ_H	horizontal-tail deflection, $\frac{\text{Left horizontal-tail deflection} + \text{Right horizontal-tail deflection}}{2}$, deg
δ_S	longitudinal side-located-stick position
δ_V	vertical-tail deflection, deg
θ	pitch attitude, deg
ξ	ratio of actual damping to critical damping
φ	bank attitude, deg

INSTRUMENTATION

The following quantities pertinent to this investigation were recorded on NASA internal-recording instruments synchronized by means of a common timer:

Airspeed and pressure altitude

Normal and longitudinal acceleration

Rolling, yawing, and pitching velocity

Angle of attack and angle of sideslip

Aileron, vertical tail, horizontal tail, and flap deflection

The airspeed and pressure altitude were measured with an NASA pitot-static tube mounted on the nose boom. Also on the nose boom were free-floating vanes used to measure angle of attack and sideslip. The angles presented were not corrected for errors induced by aircraft pitching, rolling, or yawing motions. The angular velocities were referenced to the body axis of the airplane. Angles of bank and pitch were obtained by integrating the angular velocities of roll and pitch.

An Air Force Missile Test Center Model II tracking radar with angular accuracies of 1 mil and range accuracies of 10 to 15 yards, and Askania Cine-Theodolite cameras operated by personnel of the Air Force Flight Test Center were used to determine the space position of the airplane in flight. For more precise position data and rates of sink near ground level, Air Force Flight Test Center-operated Akeley cameras were used. Photographic coverage by North American Aviation also aided in the analysis of this first X-15 flight.

AIRPLANE

The X-15, a single-place airplane designed for flight research at extremely high speeds and altitudes, is carried aloft under the right wing of a B-52 mother aircraft. The 5-percent-thick midwing of the X-15 is of trapezoidal plan form with an aspect ratio of 2.5. It is fitted with hydraulically operated plain trailing-edge flaps. All aerodynamic control surfaces are actuated by irreversible hydraulic systems. Longitudinal control is provided by deflection of the slab-type horizontal tail; lateral control is provided by differential deflection of the left and right portions of the horizontal tail. The movable portions of the upper and lower wedge-sectioned vertical tails provide directional control; however, the lower movable section (indicated by the dashed line in fig. 1) is jettisoned prior to landing for proper ground clearance. Speed brakes are located on the rear fixed portion of the upper and lower vertical tails. Auxiliary damping is provided about all three axes in a conventional manner along with a "yar" damper. The yar damper provides a crossfeed of the yaw-rate signal into the roll damper. The landing gear consists of a dual-wheel nose gear and two rear-mounted landing skids. Extension of the gear is primarily by action of gravity and airloads; however, the nosewheel-extension system does include an initiator and actuator to insure positive nose-gear lowering.

A three-view drawing and a photograph of the airplane are shown in figures 1 and 2, respectively. Pertinent physical characteristics are presented in table I.

TEST CONFIGURATION

In the flight configuration the lower jettisonable vertical tail was in place and the landing gear was retracted. The auxiliary damping system was on, with the exception of the pitch mode. The usable weight carried in this configuration included only the hydrogen peroxide, liquid nitrogen, and source gas required for airplane subsystem operation. The launch weight was 13,452 pounds with a center-of-gravity position of 18.1 percent of the mean aerodynamic chord. After the lower vertical tail was jettisoned later in the flight, the weight was reduced by about 150 pounds and the center of gravity moved forward to about 17 percent of the mean aerodynamic chord. At landing, with the gear down, the weight was 13,234 pounds with a center-of-gravity position of 17.4 percent of the mean aerodynamic chord.

RESULTS AND DISCUSSION

The general flight plan for the first flight of the X-15 is indicated in figure 3, which presents the geographical path over the ground with respect to Rosamond and Rogers Dry Lakes. Since the gliding capability of the X-15, from launch conditions of $M = 0.8$ at an altitude of 38,000 feet, is limited to a range on the order of 15 nautical miles if a relatively normal landing pattern is anticipated, the launch must be initiated much nearer the intended landing point than was done with previous rocket airplanes. For the first flight, the launch point was to be south of Rosamond Dry Lake, the in-flight maneuvering between the two dry lakes, and the landing to the north on the main north-south runway on Rogers Dry Lake. Should any unforeseen event occur at launch or during the flight, the pilot would have the best possible selection of landing points on either dry lake.

As shown in figure 3, the launch took place at the planned position. After launch recovery, the pilot performed a gradual deceleration trim run; the speed was then increased and the airplane characteristics with flaps down were evaluated. After the flaps were retracted, speed was increased and a turn was made into the downwind leg of the landing pattern.

When the airplane reached the base leg, the lower movable vertical tail was jettisoned, the turn to the runway heading was made, and the landing was accomplished. The side-located control stick was used throughout the flight. Details of the airplane characteristics from launch to landing are discussed in the following sections.

Launch Characteristics

From a motion-picture coverage of the launch taken from a rearward position on the B-52 airplane, figure 4 was prepared to give a picto- H
rial indication of the launch characteristics. In this figure at 1
$t = 0$ second the X-15 is shown in place attached to the B-52 pylon. 4
The tip of the X-15 upper vertical tail is well above the B-52 wing. 4
The static clearance between the X-15 vertical tail and the B-52 wing cutout is about 2 feet. At $t \approx 0.1$ second after launch initiation the vertical separation is about 1 foot, as indicated by the light space between the B-52 pylon and the X-15 upper fuselage, and a bank angle of about 5° has developed. At $t \approx 0.2$ second, the X-15 upper vertical tail is essentially clear of the B-52 wing, vertical separation has increased to about 4 feet, and bank angle has increased to about 10°. It is estimated that the X-15 vertical tail cleared the B-52 wing cutout by about 1 foot. At $t \approx 0.3$ second, the vertical separation has increased to about 8 feet, the X-15 has dropped below the level of the B-52 inboard-engine pod, and the bank angle has increased to about 15°.

A time history of pertinent quantities measured during the launch is presented in figure 5. Wind-tunnel results (ref. 2) indicated that an abrupt right roll would occur at launch with the airplane empty, even though all control surfaces were at zero deflection. It is apparent from the figure that the right roll occurred in flight as predicted. Although the initial rolling acceleration and peak rolling velocity of about 40° per second and the maximum bank angle of about 30° were of greater magnitude than predicted, these characteristics were acceptable. The abrupt corrective aileron deflection noted at launch was primarily caused by the roll damper rather than by pilot input.

Separation from the B-52 occurred more rapidly than predicted by wind-tunnel studies (ref. 2). Preliminary analysis of motion-picture and internal flight records indicates very little vertical displacement of the B-52 wing at the time of launch, so that the separation distance shown in figure 5 may be a reasonably accurate indication of the vertical descent of the X-15. Maximum excursion in pitch at launch was to about -1 g with a corresponding angle of attack of about -6°. After launch the pilot moved the longitudinal control to about 5° airplane nose up, as required to trim at launch conditions. Trim-flight conditions were achieved in less than 10 seconds after launch with no loss in airspeed and with less than a 1,000-foot loss of altitude. Directional stability was good and little yawing motion was noted.

Low-Speed Characteristics

Following launch recovery, a gradual deceleration trim run was made at a relatively constant altitude of 35,000 feet. A time history of some of the parameters measured during the deceleration is presented in figure 6. The speed change shown was from about 250 to 180 knots indicated airspeed. The angle of attack changed from about 8° to 12° with a corresponding change in normal-force coefficient from about 0.4 to 0.7. The onset of buffet occurred at a normal-force coefficient of about 0.6 for an airspeed equivalent to $M = 0.6$. The normal-force coefficient for onset of buffet increased slightly with decreasing speed and compared reasonably well with buffet predictions.

Positive static longitudinal stability was evident to the pilot and is also evident in figure 6. No apparent change in static longitudinal stability or directional stability with increasing angle of attack was indicated to the pilot or shown by the data. To the pilot, the continuing oscillation in pitch was indicative of low damping; however, it was estimated that the damping of the controls-fixed airplane should be appreciable ($\xi \approx 0.25$). The consistent longitudinal-control motions used by the pilot with the side-located control stick are apparently sufficient excitation to prevent the oscillation from being damped out.

A time history of quantities measured during the flap evaluation is presented in figure 7. This evaluation was made at an indicated airspeed of about 180 knots and above an altitude of about 30,000 feet. Flap deflection required 10 seconds. The increase in lift due to flap deflection required that the trim angle of attack be reduced from about 10° to 7°. The pilot reported no appreciable buffet with the flaps down and no noticeable difference in airplane characteristics between the clean configuration and the flaps-down configuration. It should be pointed out that the pitching oscillation was apparently not affected by flap deflection.

A time history of quantities measured during the turn into the downwind leg of the landing pattern is shown in figure 8. An attempt was made to hold speed relatively constant at about 270 knots ($M \approx 0.6$) by losing altitude, which decreases from about 22,000 feet to 18,000 feet. Maximum normal acceleration attained was greater than 2g, with a corresponding normal-force coefficient of about 0.6 and a maximum angle of attack of about 11°. Buffet onset was reported at 2g by the pilot, and the flight records indicated this to occur at about the same Mach number of 0.6 and normal-force coefficient of approximately

0.6 as reported during the deceleration trim run. The apparent static longitudinal stability is about that which was expected; however, no stick-force measurement was available. The amplitude and period of the pitching oscillation appear to be little affected by increasing load factor.

Good directional characteristics were reported by the pilot. Furthermore, little yawing moment was induced by the rolling tail for the low deflections used, and the sideslip angle resulting from roll control is indicated to be favorable.

Landing Characteristics

Prior to a discussion of the X-15 landing characteristics, the lift-drag-ratio characteristics of the airplane should be reviewed. Since the predicted values of lift-drag ratio, particularly in the landing configuration, were appreciably lower than had been experienced with previous rocket airplanes, much effort was expended by North American, the Air Force, and NASA in both analytical and flight programs to determine the effect of these low values of lift-drag ratio on the techniques employed in the landing.

Comparisons of the predicted and flight-measured lift-drag-ratio characteristics of the X-15 are presented in figures 9 and 10 for the clean configuration and the landing configuration, respectively. Maximum predicted values of lift-drag ratio were about 4 for the clean configuration and 3 for the landing configuration. The flight data for the clean configuration (fig. 9) were obtained from the maneuvers previously described. The correlation of the data indicates that the lift-drag ratios were reasonably well predicted. Comparison between the predicted and flight-measured lift curve is also shown in figure 9, and good correlation is evident.

Since severe transient conditions existed in the landing configuration, as is shown in a subsequent figure, only limited data were considered suitable for presentation (fig. 10). The correlation between the flight-measured and predicted lift-drag ratios is believed to be qualitative; however, additional data in the landing configuration will be required to verify the predicted lift-drag ratio and lift curve.

One purpose of the preflight analytical and flight programs was the determination of the type of pattern best suited to a configuration of low lift-drag ratio, such as the X-15. It was determined that a circular pattern flown at a relatively constant speed and bank angle offered the pilot sufficient flight-path control to facilitate landing at the desired touchdown point. The actual landing pattern traversed by the X-15 is shown in figure 11. The plan and profile views of the pattern are shown in terms of distances away from the touchdown point at time 0. The airplane was on the downwind leg at an altitude of about 10,000 feet at about 100 seconds prior to touchdown. The altitude had decreased to about 5,000 feet at the base leg where the lower vertical tail was jettisoned with about 60 seconds remaining. The turn to the final runway heading was completed at about 1,500 feet where initial flare was started about 30 seconds prior to landing. The pilot estimated the bank angle to be 30° to 40° during the pattern; shortly after entering the pattern, the airspeed was increased to a relatively constant value of about 270 knots until initial flare when it was gradually decreased to about 150 knots at touchdown. For comparison, predicted patterns are shown for a constant speed of 255 knots and constant bank angles of 30° and 45° (fig. 11). Other than a slightly tighter pattern initially, which may have been caused by a higher flight speed or bank angle, the flight pattern compares well with the predicted pattern for a bank angle of 30°. If the bank angle in flight had been closer to 45°, the pattern obviously would have been tighter and lower.

Pertinent quantities measured during the pattern are shown in figure 12. The maximum measured rate of sink of about 170 feet per second occurred during the base-leg turn just prior to jettison of the lower vertical tail, which produced no unusual characteristics. The angle of attack prior to flare was on the order of 6° to 7°, and the excursions in sideslip angle throughout the approach and landing were minor. Speed did not start to bleed off until the altitude had decreased to about 1,000 feet.

The flare and touchdown are shown in more detail in figure 13. At flare initiation, which occurred at an altitude of about 1,500 feet, the rate of sink was about 130 feet per second and was reduced to levels below 10 feet per second in the final 10 seconds of flight. The level of normal acceleration used in the initial flare was about 1.25g. Flap deflection occurred as the altitude decreased from about 700 feet to 200 feet. The gear was down and locked at an altitude of about 80 feet, and touchdown occurred at about 150 knots. The rates of sink of about 2 feet per second for main-gear contact and 13.5 feet per second for nose-gear contact (approximately 0.5 second later) are well within gear-design limitations. Although the airplane did a mild turn during the ground runout over a distance of about 4,000 feet, good stability was indicated.

From figure 13 it is obvious that a severe pitching oscillation was induced near the end of the flap cycle. Reduced longitudinal trim was required as the flaps were being deflected, and the pilot added further airplane nose-down trim to avoid flaring too high. Apparently the oscillation became more severe because of the control input at about 18 seconds before touchdown. From this point, the pilot was not able to anticipate the oscillation accurately, which may have been aggravated by the fact that the control surface was rate-limited to 15° per second. Although the pilot originally intended to land at an airspeed of about 180 knots, the speed decreased another 30 knots before the touchdown could be accomplished. The transients in pitch covered an angle-of-attack range from -1° to 13°, with the amplitude as high as $\pm 5^{\circ}$. The corresponding amplitude in normal acceleration was nearly ± 1 g. Additional factors which may have aggravated the controllability problem include the lack of a pitch damper, a nonlinear airplane pitching moment with near-neutral stability at low angle of attack, and a sensitive side-located control stick.

H
1
4
4

Figure 13 also shows a typical analog simulator run of a landing in which the flaps and landing gear were lowered at an altitude close to the ground. The airspeed for the predicted case is somewhat higher than in flight; however, there is reasonably good correlation between predictions and flight in altitude and rate of sink.

CONCLUSIONS

From data evaluation and pilot comments obtained during the first flight of the North American X-15 research airplane, the following conclusions can be made:

1. The X-15 airplane effected satisfactory separation from the B-52 wing-mounted pylon with little yawing motion, but with noticeable rolling and pitching motions.

2. The actual pattern and landing characteristics compared favorably with predicted characteristics, and the recommended landing technique of lowering the flaps and landing gear at a low altitude appears to be a satisfactory method of landing the X-15 airplane. There was a quantitative correlation between flight-measured and predicted lift-drag-ratio characteristics in the clean configuration and a qualitative correlation in the landing configuration.

3. A longitudinal-controllability problem, apparently aggravated by the sensitivity of the side-located control stick, was evident throughout the flight and became severe in the landing configuration.

4. The longitudinal and directional stability were indicated to be adequate in the low-to-moderate angle-of-attack range.

5. The characteristics of the rolling tail appeared satisfactory for the small deflections used.

6. Buffet onset occurred at a normal-force coefficient of about 0.6 at a Mach number of about 0.6.

High-Speed Flight Station,
National Aeronautics and Space Administration,
Edwards, Calif., August 25, 1959.

REFERENCES

1. Matranga, Gene J., and Armstrong, Neil A.: Approach and Landing Investigation at Lift-Drag Ratios of 2 to 4 Utilizing a Straight-Wing Fighter Airplane. NASA TM X-31, 1959.

2. Alford, William J., Jr., and Taylor, Robert T.: Aerodynamic Characteristics of the X-15/B-52 Combination. NASA MEMO 6-8-59L, 1959.

TABLE I.- PHYSICAL CHARACTERISTICS OF THE AIRPLANE

Wing:	
Airfoil section	NACA 66005 (Modified)
Total area (includes 94.98 sq ft covered by fuselage), sq ft	200
Span, ft	22.36
Mean aerodynamic chord, ft	10.27
Root chord, ft	14.91
Tip chord, ft	2.98
Taper ratio	0.20
Aspect ratio	2.50
Sweep at 25-percent-chord line, deg	25.64
Incidence, deg	0
Dihedral, deg	0
Aerodynamic twist, deg	0
Flap -	
Type	Plain
Area (each), sq ft	8.30
Span (each), ft	4.50
Inboard chord, ft	2.61
Outboard chord, ft	1.08
Deflection, down, deg	40
Ratio flap chord to wing chord	0.22
Ratio total flap area to wing area	0.08
Ratio flap span to wing semispan	0.40
Trailing-edge angle, deg	5.67
Sweepback angle of hinge line, deg	0
Horizontal tail:	
Airfoil section	NACA 66005 (Modified)
Total area (includes 63.29 sq ft covered by fuselage), sq ft	115.34
Span, ft	18.08
Mean aerodynamic chord, ft	7.05
Root chord, ft	10.22
Tip chord, ft	2.11
Taper ratio	0.21
Aspect ratio	2.83
Sweep at 25-percent-chord line, deg	45
Dihedral, deg	-15
Ratio horizontal-tail area to wing area	0.58
Movable surface area, sq ft	51.77
Deflection -	
Longitudinal, up, deg	15
Longitudinal, down, deg	35
Lateral differential (pilot authority), deg	±15
Lateral differential (autopilot authority), deg	±30
Control system	Irreversible hydraulic boost with artificial feel
Upper vertical tail:	
Airfoil section	10° single wedge
Total area, sq ft	40.91
Span, ft	4.58
Mean aerodynamic chord, ft	8.95

TABLE I.- PHYSICAL CHARACTERISTICS OF THE AIRPLANE - Concluded

Root chord, ft	10.21
Tip chord, ft	7.56
Taper ratio	0.74
Aspect ratio	0.51
Sweep at 25-percent-chord line, deg	23.41
Ratio vertical-tail area to wing area	0.20
Movable surface area, sq ft	26.45
Deflection, deg	±7.50
Sweepback of hinge line, deg	0
Control system	Irreversible hydraulic boost with artificial feel
Lower vertical tail:	
Airfoil section	10° single wedge
Total area, sq ft	34.41
Span, ft	3.83
Mean aerodynamic chord, ft	9.17
Root chord, ft	10.21
Tip chord, ft	8
Taper ratio	0.78
Aspect ratio	0.43
Sweep at 25-percent-chord line, deg	23.41
Ratio vertical-tail area to wing area	0.17
Movable surface area, sq ft	19.95
Deflection, deg	±7.50
Sweepback of hinge line, deg	0
Control system	Irreversible hydraulic boost with artificial feel
Fuselage:	
Length, ft	50.75
Maximum width, ft	7.33
Maximum depth, ft	4.67
Maximum depth over canopy, ft	4.97
Side area (total), sq ft	215.66
Fineness ratio	10.91
Speed brake:	
Area (each), sq ft	5.57
Span (each), ft	1.67
Chord (each), ft	3.33
Deflection, deg	35

	Launch	Landing
Weight, lb	13,452	13,234
Center-of-gravity location, percent mean aerodynamic chord	18.1	17.4
Moments of inertia:		
I_X, slug-ft^2	3,400	3,400
I_Y, slug-ft^2	79,000	77,900
I_Z, slug-ft^2	80,800	79,600

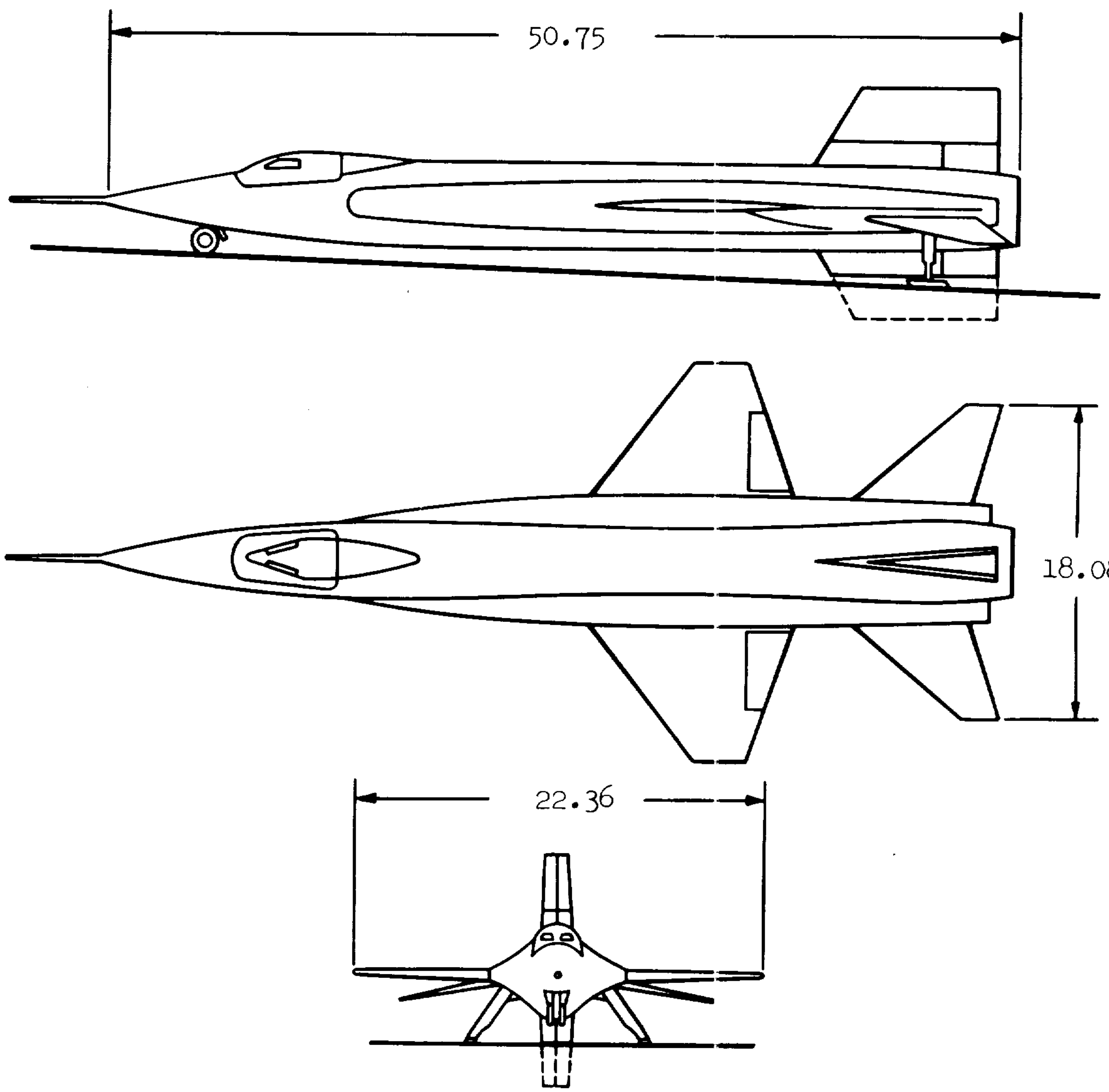


Figure 1.- Three-view drawing of the test airplane. All dimensions in feet.

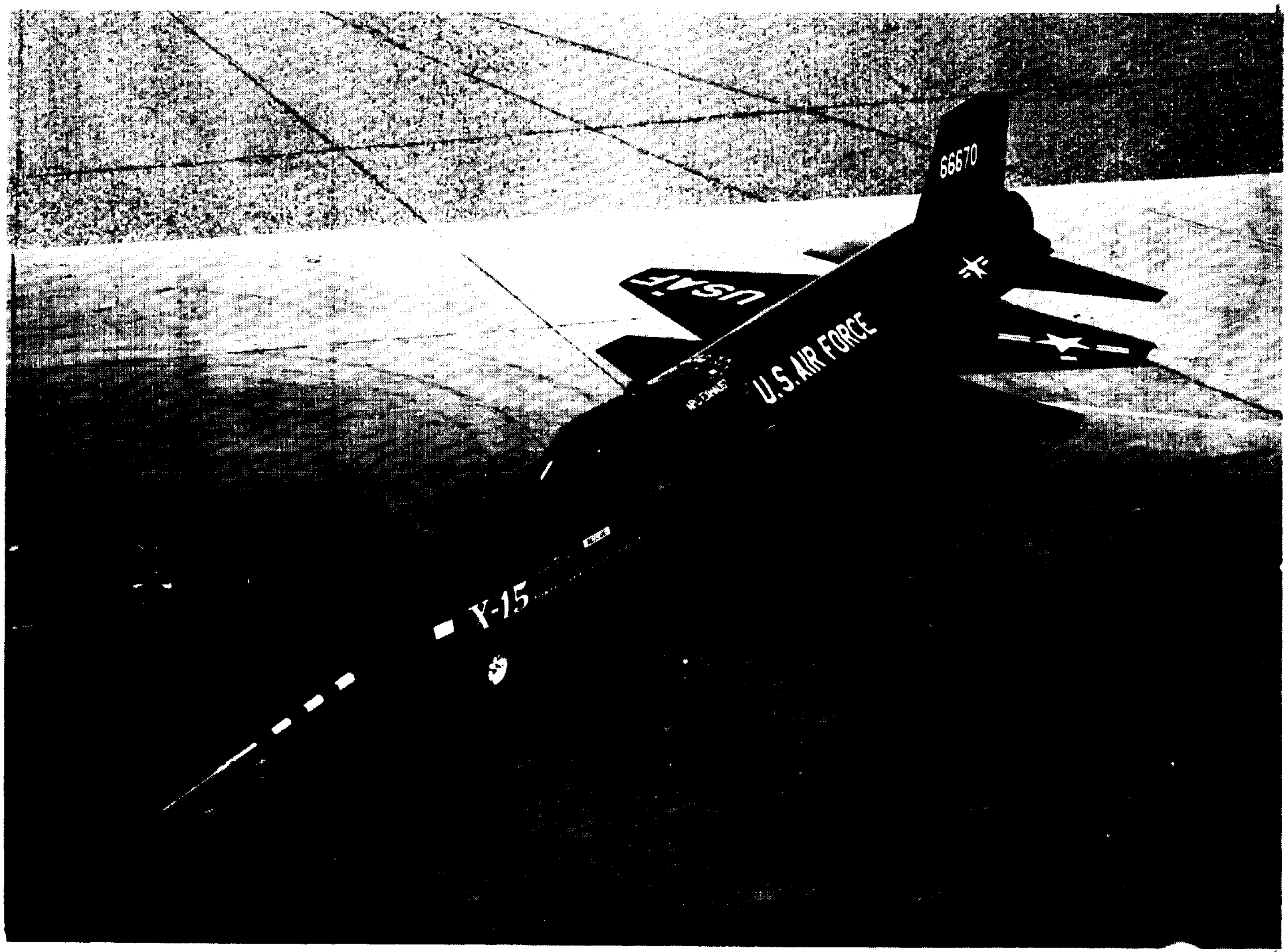


Figure 2.- Photograph of the X-15 airplane. L-59-6021

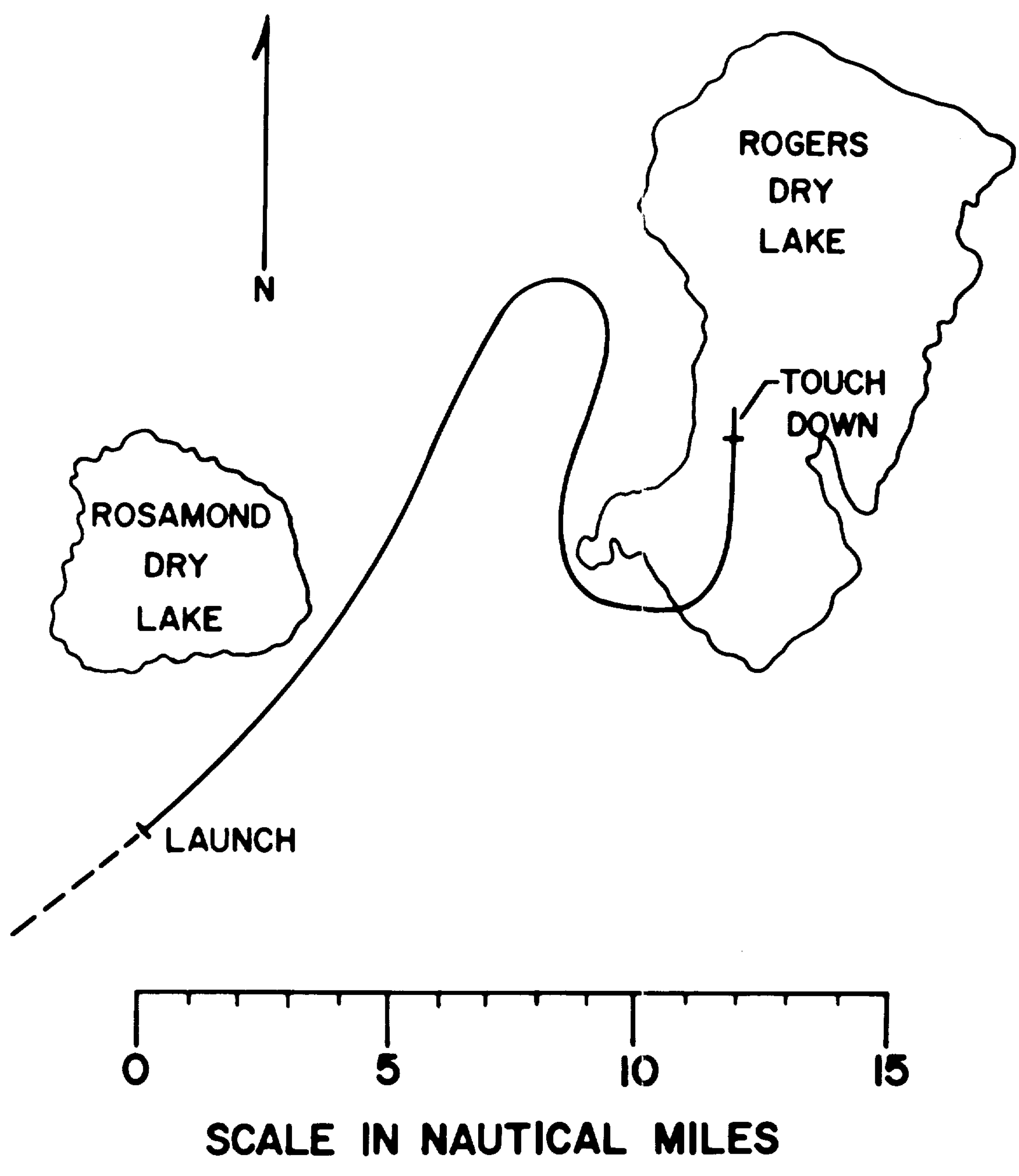
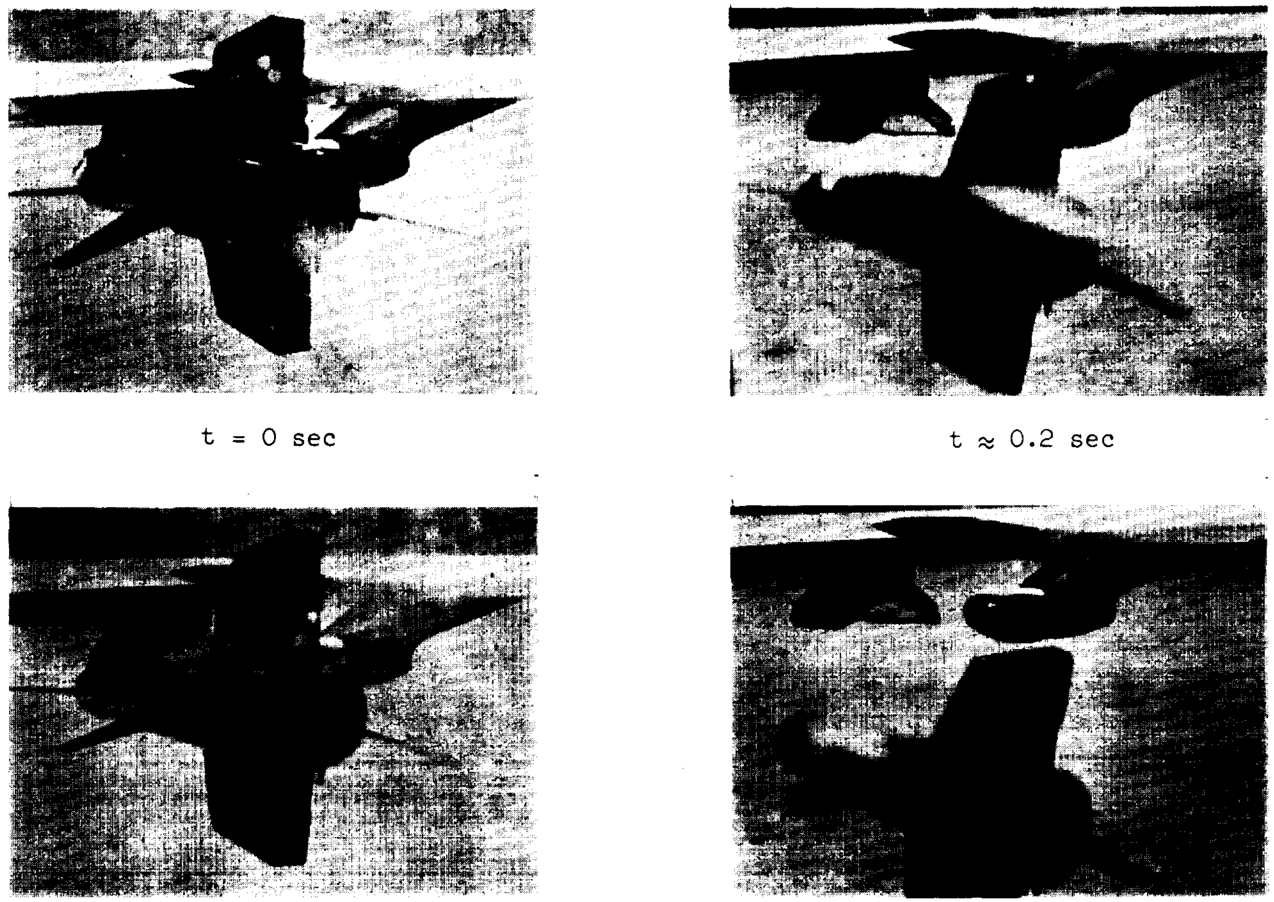


Figure 3.- General flight plan of the first X-15 flight.



$t = 0$ sec

$t \approx 0.2$ sec

$t \approx 0.1$ sec

$t \approx 0.3$ sec

L-59-6022

Figure 4.- Photographs of the X-15 airplane taken during launch from a rearward camera station on the B-52 airplane.

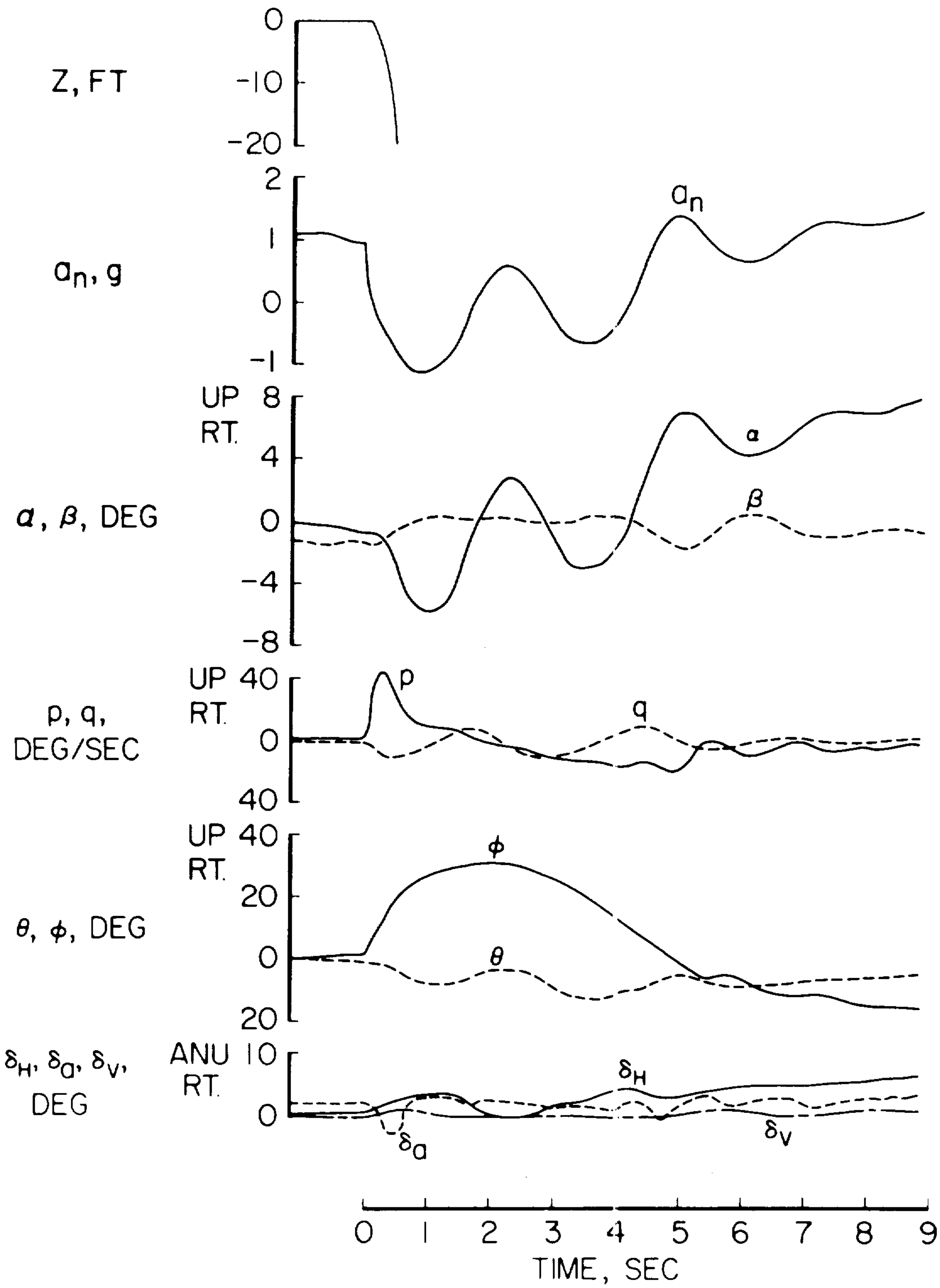


Figure 5.- Time history of the launch.

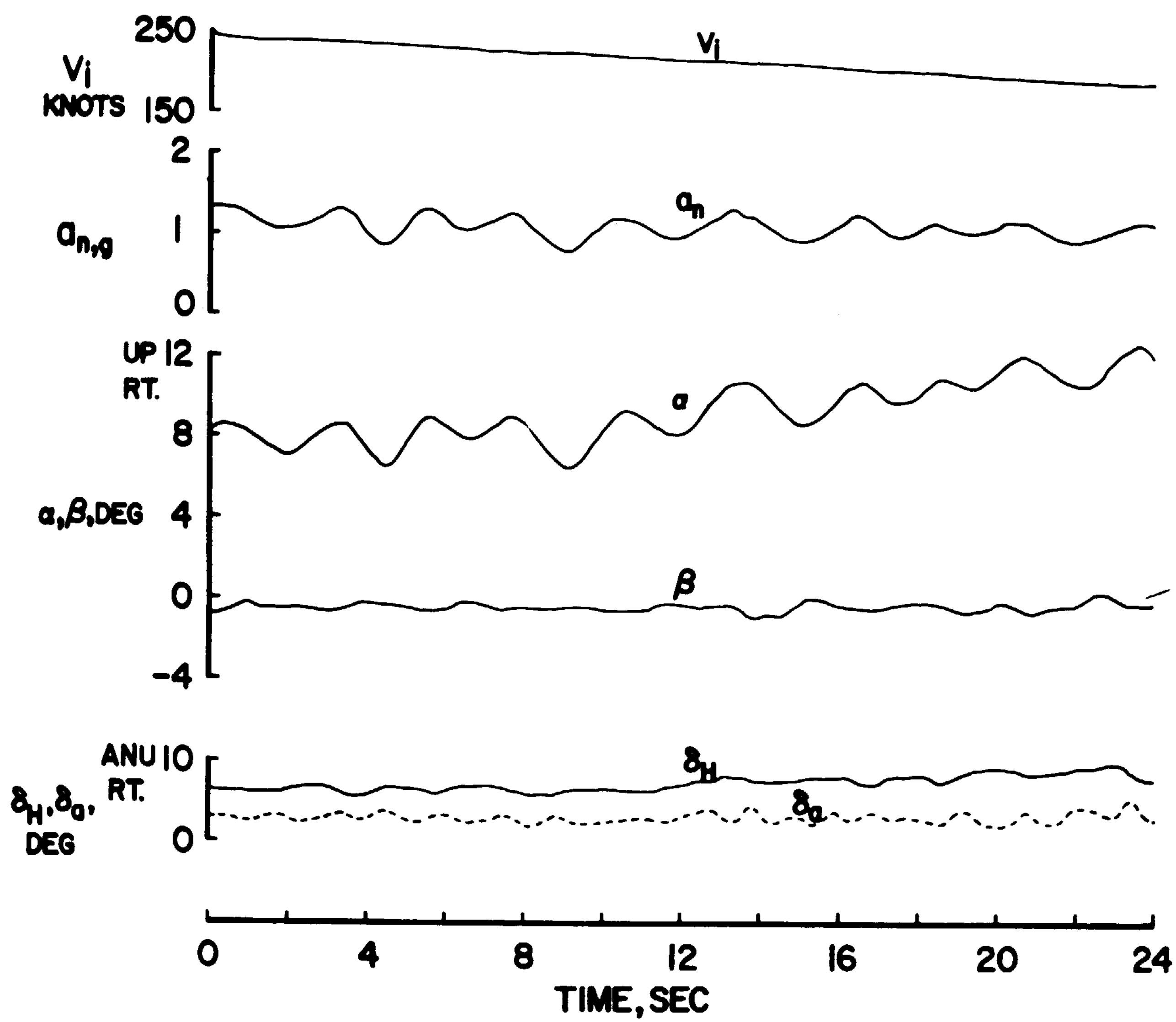


Figure 6.- Time history of the deceleration trim run.

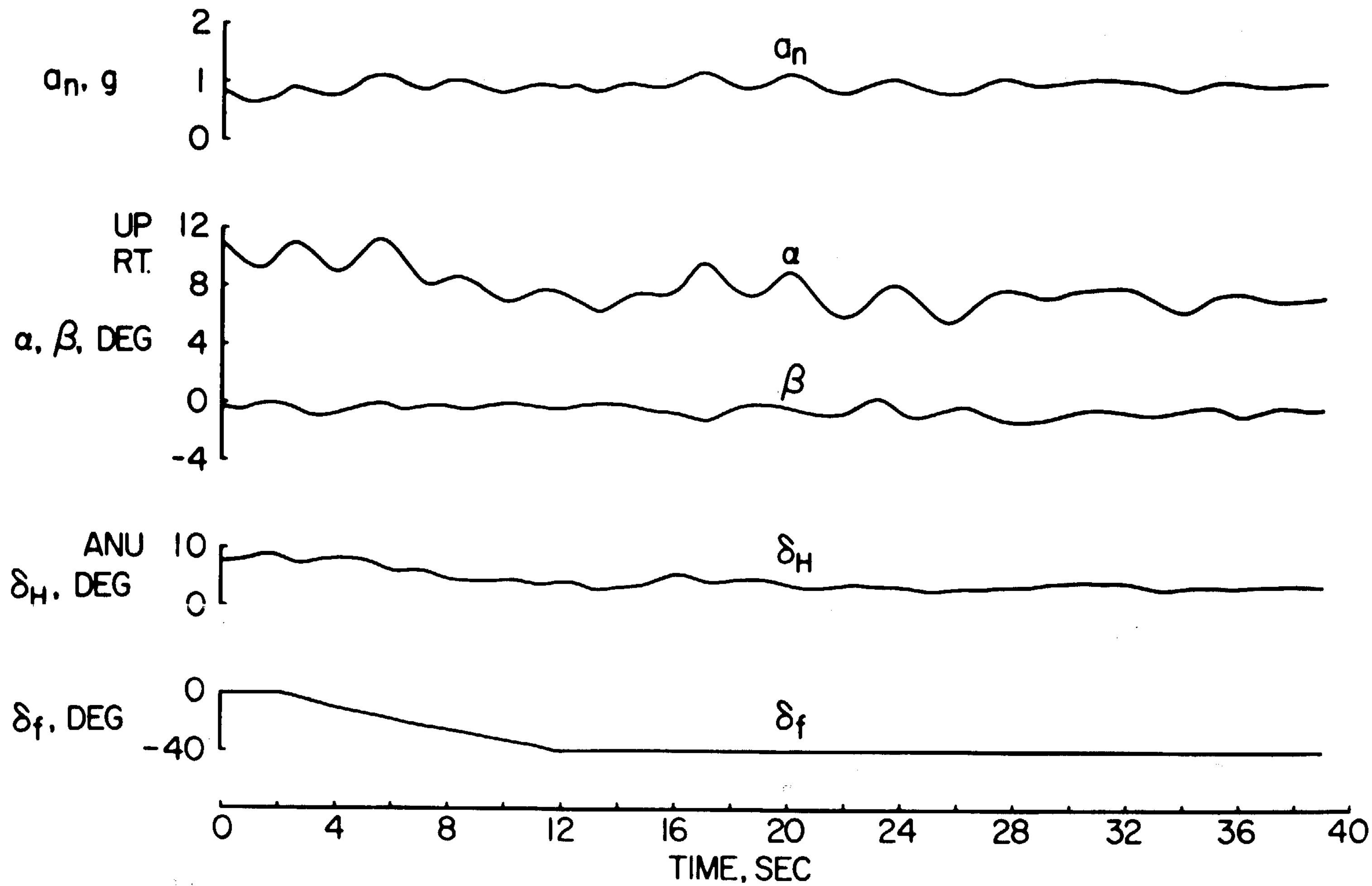


Figure 7.- Time history of the flap evaluation.

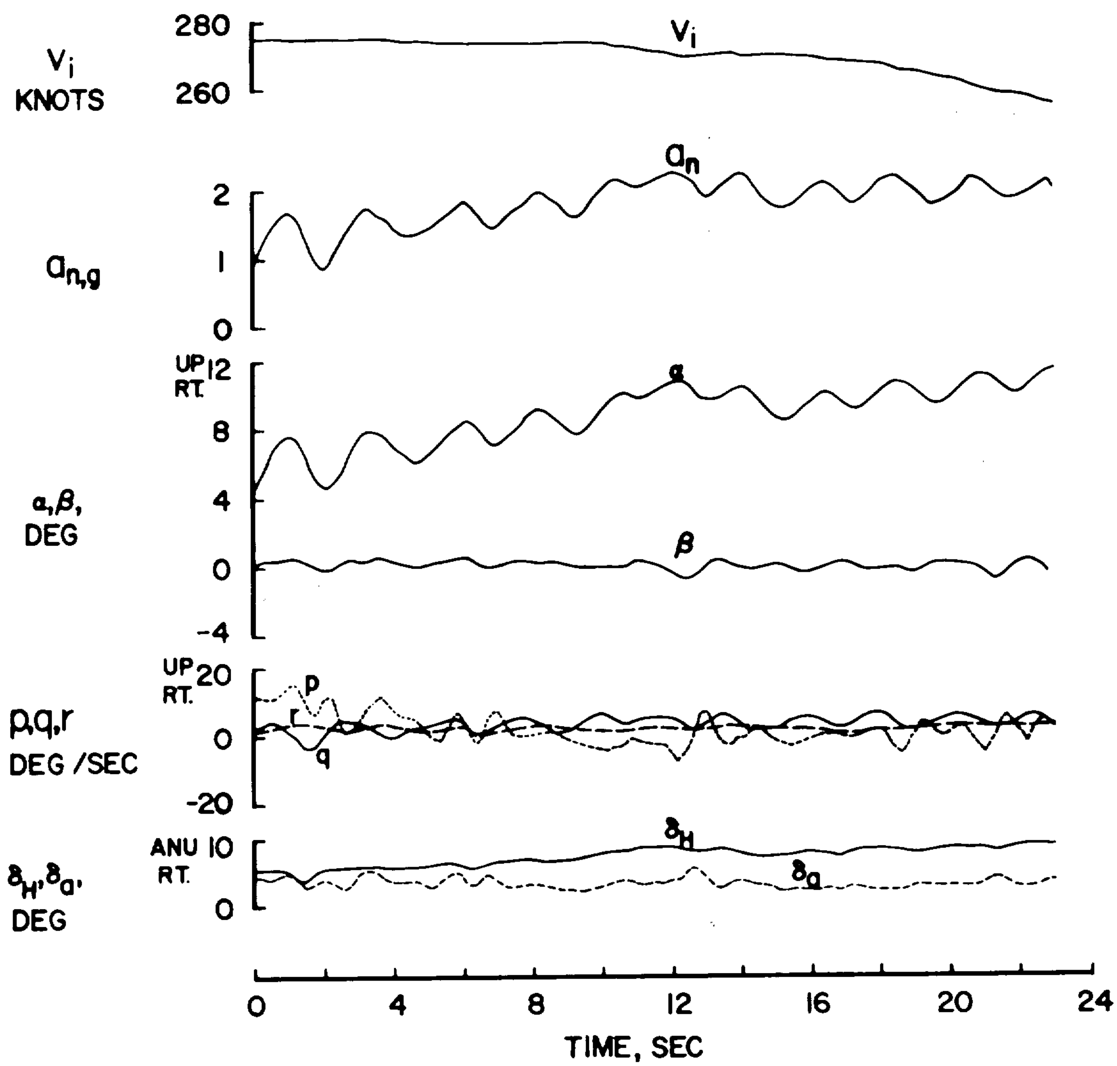


Figure 8.- Time history of a turn made prior to landing-pattern entry.

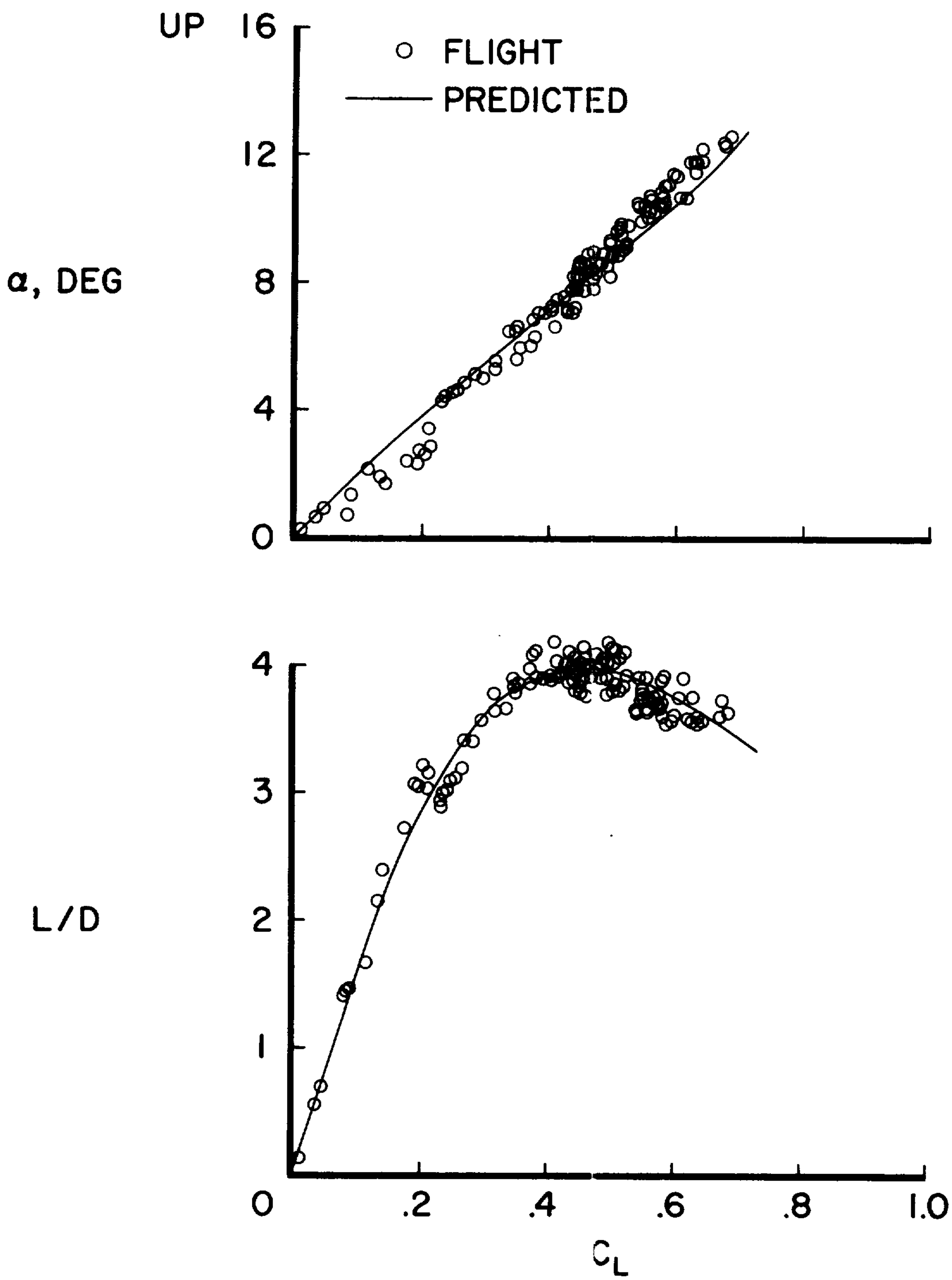


Figure 9.- Comparison of flight-measured and predicted lift-curve and lift-drag ratios in the clean configuration.

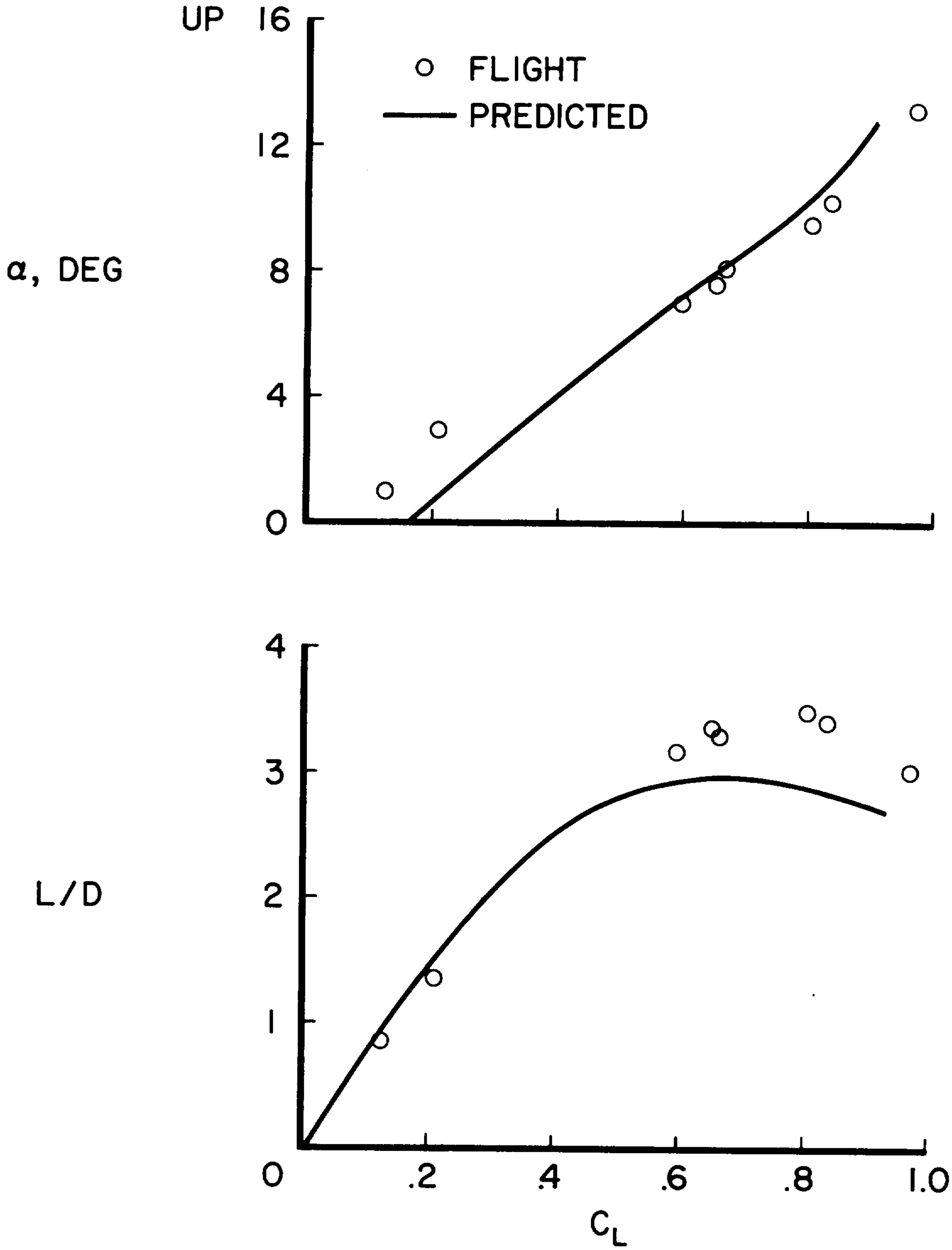


Figure 10.- Comparison of flight-measured and predicted lift-curve and lift-drag ratios in the landing configuration.

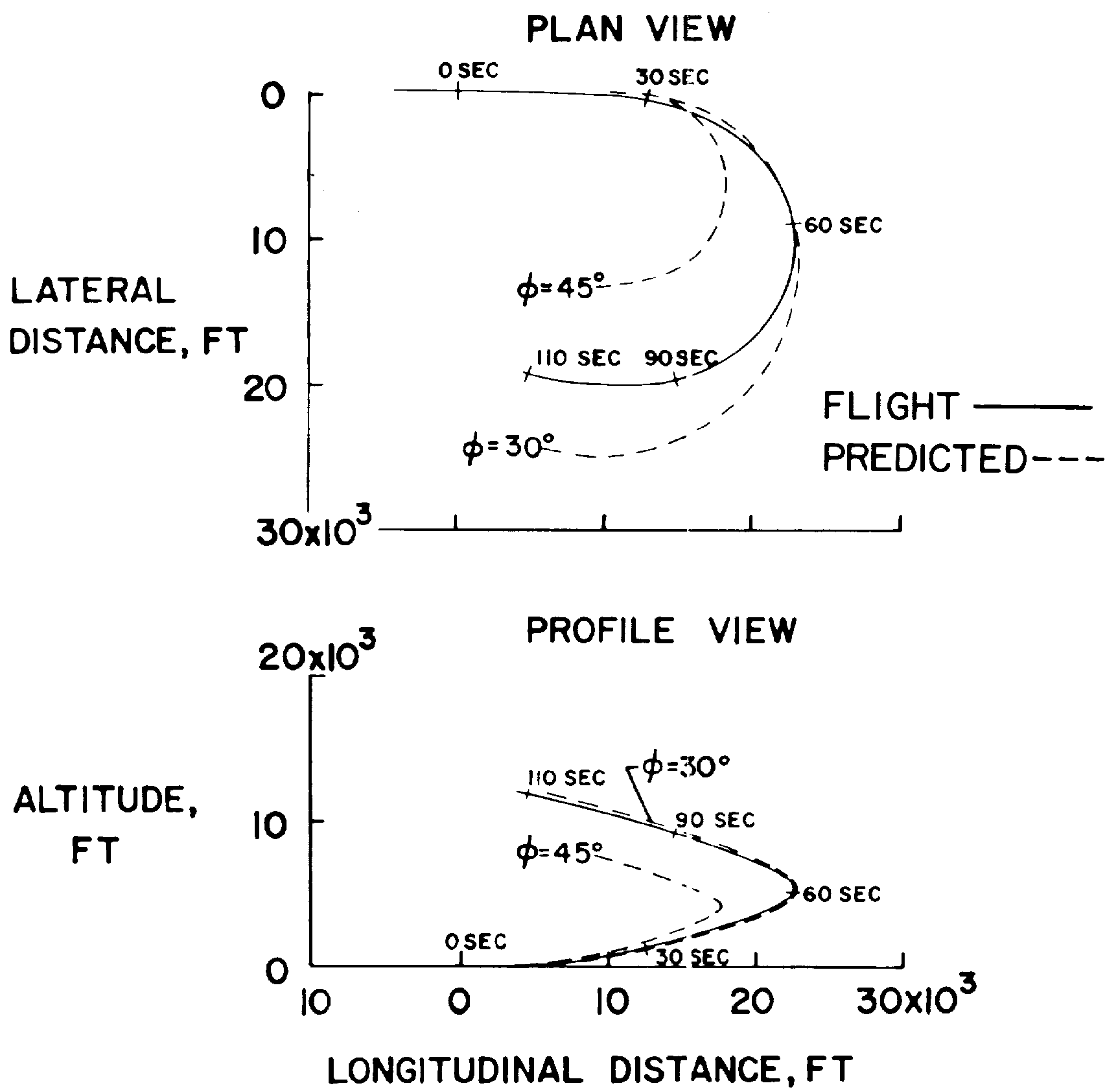


Figure 11.- Comparison of flight and predicted landing patterns for the X-15.

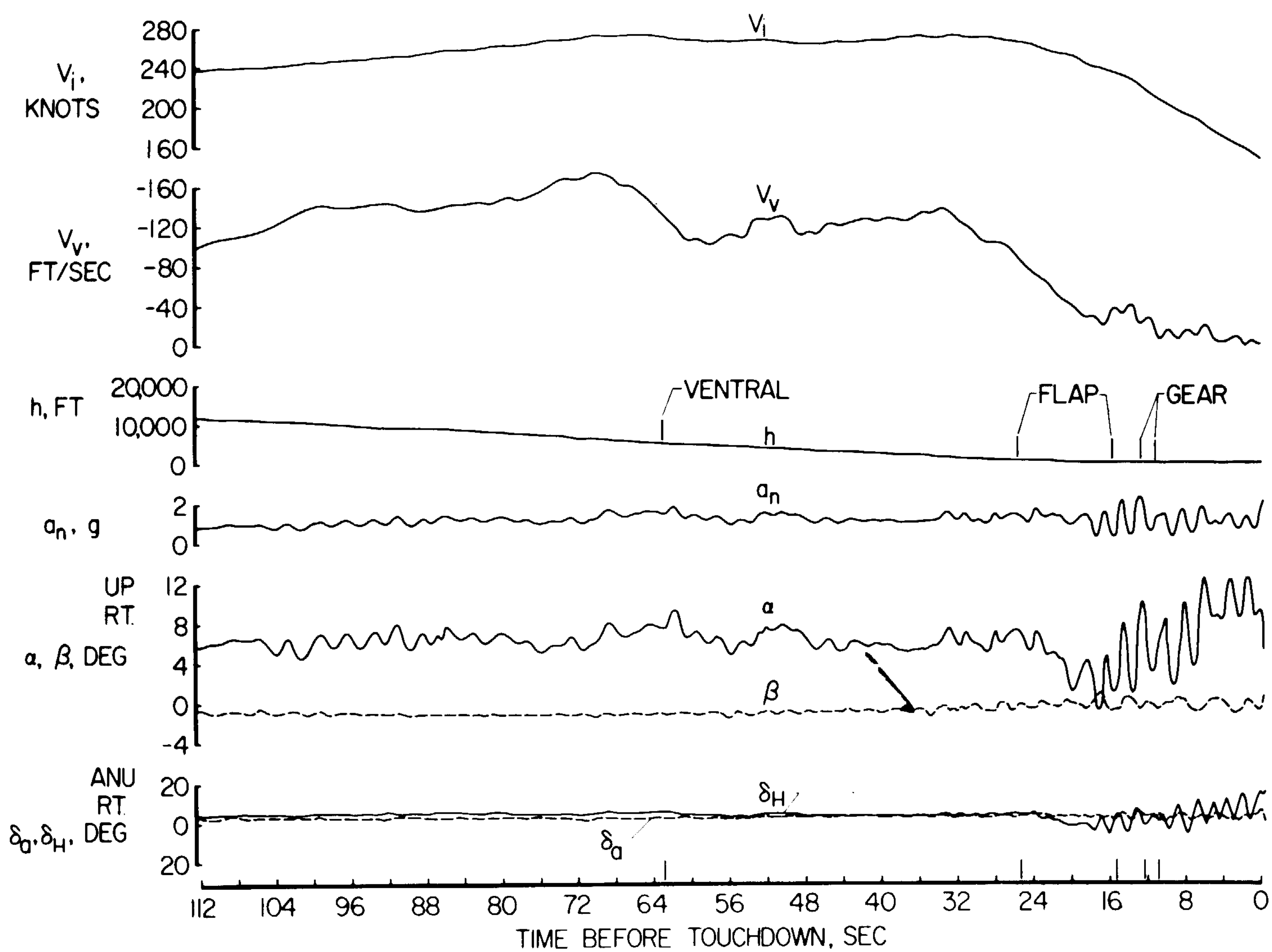


Figure 12.- Time history of the approach and landing.

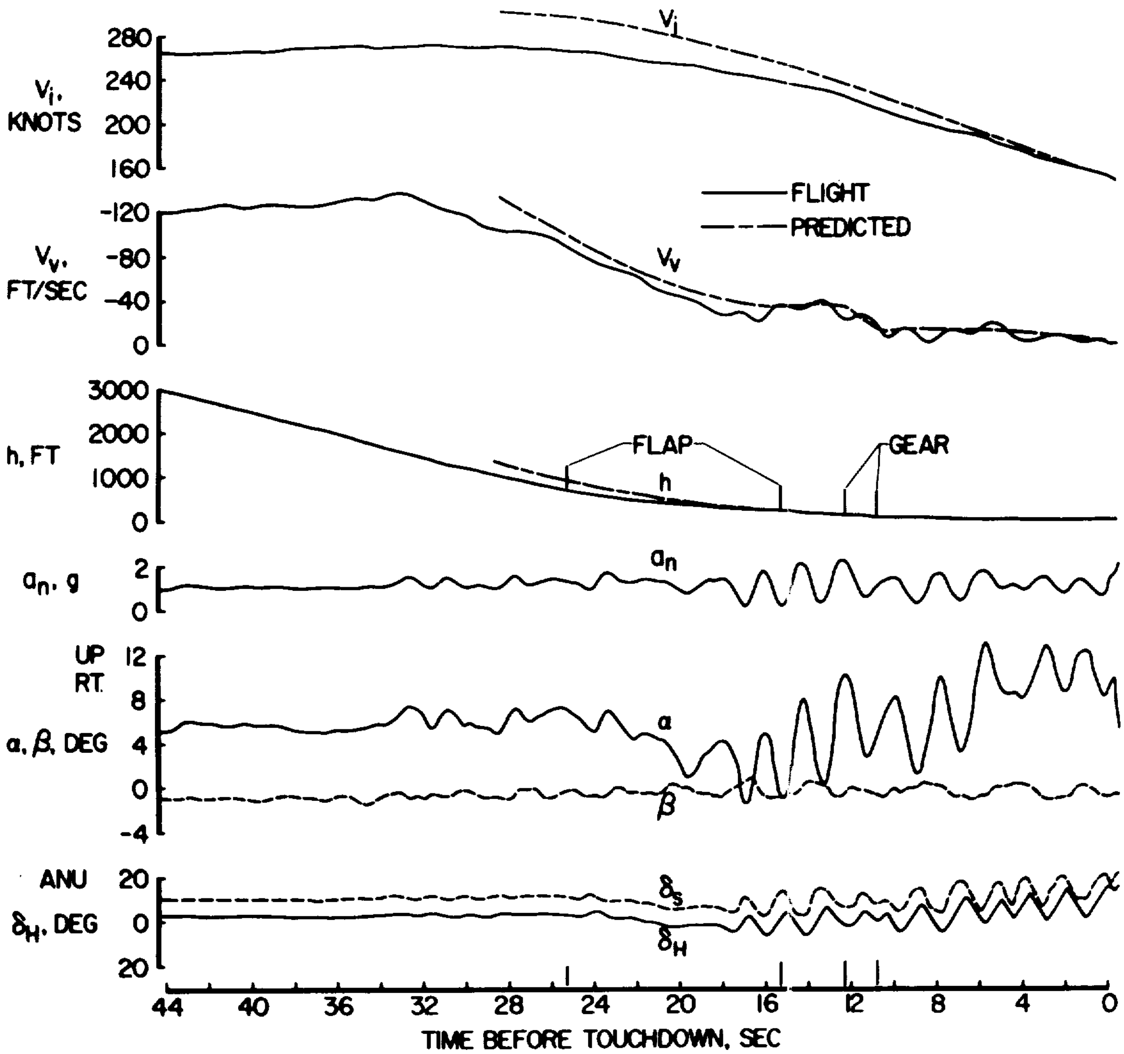


Figure 13.- Time history of the flare and touchdown.